THE EFFECT OF ENVIRONMENTAL FACTORS ON THE DISTRIBUTION OF IMMATURE *CULEX ANNULIROSTRIS* SKUSE (DIPTERA: CULICIDAE)

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Abstract
Observations were made on the distribution of immature *Culex annulirostris* in a drainage channel at Charleville in south-western Queensland. Highest densities were found in still waters supporting a moderate or dense growth of *Paspalum* spp. which was shaded for part of the day. Density was independent of water depth (6-10 cm cf. 11-15 cm) in the presence of *Paspalum* spp. but was higher in water 11-15 cm deep when *Cenchrum ciliaris* L. was the dominant grass. In this depth of water *C. ciliaris* had more leaves on the surface and was more branched under water.

Introduction
Culex annulirostris is a common pest mosquito in Australia and the vector of Murray Valley Encephalitis and Ross River virus to humans (Doherty, 1977), and heartworm (*Dirofilaria immitis* (Leidy)) to dogs (Russell, 1985). Its breeding sites have been described as fresh-water swamps, transient grassy pools in shade or sunlit and usually with aquatic or emergent vegetation (Kay *et al.* 1981). No quantitative data have been published on the relationship between these environmental variables and abundance of immature *Cx annulirostris*. In this study we evaluate the effect of water depth, speed of water flow, degree of shading, and species and density of grass on the distribution of immature *Cx annulirostris* at one site.

Methods
Observations were made on a side channel leading from the cleanest sewage treatment pond (No. 4) at Charleville (26°24'S, 146°15' E) in south-western Queensland. The channel was about 1.7 m wide with both banks covered with *C. ciliaris*, *Paspalum distichum* L. and a *Paspalum* sp. The middle of the channel was almost free of grass where the water flowed quite fast but at the banks it was slow flowing or still. Water depth varied from 7 to 15 cm.

Samples were taken close to the banks on each side of the channel at 36 evenly spaced positions (60 cm apart), giving 72 sampling locations. At each location a sample was taken with a 300 ml dipper daily for 10 days (22-31 March 1980), the number of immatures recorded and the sample returned to the same spot. Samples were taken sequentially from positions 1-36 on the left bank and then on the right bank. Disturbance would show as a lower catch in sample $x+1$ compared to sample x. Using the total number of immatures observed at each location, numbers at locations $x+1$ were higher than those at x in 39 comparisons, lower on 28 and equal on 3. This suggests that disturbance was minimal.

Each location was classified as shallow (6-10 cm) or deep (11-15 cm); fast flowing, slow flowing or still; open (exposed to the sun all day), partially shaded (shaded for part of the day) or fully shaded; and the grass density as light (most parts emergent with only a few leaves touching the water), moderate (branched in the water and some leaves lying flat on the surface), or dense (branched in the water and dense cover of leaves on the surface).

For statistical analysis the data were transformed logarithmically [ln(x+1)] where x is the number of immatures. Tests of significance were carried out on means of the transformed data (M_L, Kettle and Linley 1967) using the *t*-test. In presenting the results modified geometric means (M_W, Williams mean, Haddow, 1960) have been used where M_W = antilog M_L-1. Two statistical analyses were carried out. The first looked at variance due to days, locations and banks using an ANOVA, and the second assessed the contribution of the environmental variables using a technique for unbalanced, factorial data (GLIM 3.10, Royal Statistical Society, London; Baker and Nelder, 1978).

The second analysis was complicated by the unequal frequency with which various environmental categories occurred. Thus for water depth 51 locations were shallow and 21 deep; for speed of flow - still (36), slow (35), fast (1), reducing the comparison to still v slow; shade - open (48), partial (16), full (8); grass species *C. ciliaris* (12), *P. distichum* (47), *Paspalum* sp. (13); grass density - light (15), moderate (31), dense (26).

Results and Discussion

Over the 10 days 6300 immature *Cx annulirostris* were collected with the numbers at the different locations ranging from 0 to 423 and daily totals from 293 to 934.

Table 1. Analysis of variance of numbers of immature *Cx annulirostris* on days, locations and banks. SS = Sum of squares; MS = Mean square; df = degrees of freedom; F = Variance ratio.

Source	df	SS	MS	F
Days	9	58.45	6.49	29.25***
Locations	71	628.35	8.85	39.86***
Banks	1	203.42	203.42	916.31***
Positions	35	222.05	6.34	28.58***
Banks x Positions	35	202.88	5.80	26.11***
Banks x Days	9	4.94	0.55	2.47*
Positions x Days	315	81.49	0.26	1.17
Error	315	70.06	0.22	
Total	719	843.29		

***, **, * signify probabilities of <0.001, <0.01 and <0.05 respectively.

The first analysis, using the 720 daily counts (10 days x 72 locations), found highly significant differences between days, banks and positions (Table 1). The difference between days was to be expected as it was unlikely that the numbers of eggs hatching and the numbers of adults emerging would maintain a steady population. Nearly 3 times as many immature *Cx annulirostris* were recorded from the left bank (4631) than from the right bank (1669). An explanation of this difference will be given in the next paragraph. For the present investigation the most important feature of this analysis was the highly significant bank/position interaction, indicating that the distribution of the immatures was influenced by factors other than bank and position. Some of these factors could be environmental.

Table 2. Analysis of variance of numbers of *Cx annulirostris* on various environmental factors. Only significant first order interactions have been included. For symbols see Table 1.

Source	df	SS	MS	F
Flow	1	22.81	22.81	51.61***
Grass density	2	16.91	8.45	38.21***
Grass species	2	13.77	6.89	31.15***
Shade	2	2.75	1.38	6.22**
Depth	1	0.04	0.04	0.18
Depth x grass species	2	3.03	1.50	6.80**
Depth x grass density	2	2.53	1.27	5.73**
Residual	42	9.29	0.22	
TOTAL	71	127.90		

The second analysis related the transformed total count of immatures at each location to the 5 environmental variables listed above. The most important factor affecting the distribution of immature *Cx annulirostris* was speed of flow (Table 2), followed by grass density and species and, of lesser importance, shade. Water depth in itself was unimportant but it interacted significantly with both grass species and grass density. Immature *Cx annulirostris* were five times as abundant in still compared to slow flowing water (Table 3). The larger number of *Cx annulirostris* recorded from the left bank results from the greater number of still water locations (23) on the left bank compared to the right (13).

Table 3. Effect of speed of flow and degree of shading on the numbers of immature *Cx annulirostris*. Means followed by the same letter are not significantly different. M_L and Mv_W are defined in the text.

	M_L	M_W
Still water	4.70 a	108.9
Slow flowing	3.04 b	19.9
Partly shaded	4.73 a	112.3
Open	3.97 b	52.0
Fully shaded	1.71 c	4.5

Immature *Cx annulirostris* were relatively scarce in shaded locations (4.5, Table 3), much more common (52.0) in open areas and most numerous (112.3) in partly shaded locations. They were equally abundant in shallow and deep water in the presence of *Paspalum* spp. but very scarce in shallow water where *C. ciliaris* was present (Table 4A). When *C. ciliaris* was in deep water significantly more immature *Cx annulirostris* were present and the number was lower but not significantly different from those found among the *Paspalum* spp.

Table 4. Effect on numbers of immature *Cx annulirostris* of depth of water in association with (A) Species of grass, and (B,C) Density of grass - (B) including *C. ciliaris* and (C) excluding *C. ciliaris*. Means followed by a different letter are significantly different. The letters a,b and v,w refer to vertical and horizontal comparisons respectively.

	Shallow		Deep	
	(A) Species of Grass			
	M_L	M_W	M_L	M_W
Paspalum sp.	4.39 a v	79.6	3.96 a v	51.5
P. distichum	4.27 a v	70.5	4.09 a v	58.7
C. ciliaris	1.11 b w	2.0	3.24 a v	24.5
	(B) Including *C. ciliaris*			
Grass Density	M_L	M_W	M_L	M_W
Moderate	4.68 a v	106.8	4.47 a v	86.4
Dense	3.49 b v	31.8	3.62 ab v	36.3
Light	3.26 b v	25.1	2.69 b v	13.7
	(C) Excluding *C. ciliaris*			
Moderate	4.71 a v	111.1	4.67 a v	106.7
Dense	4.43 a v	83.9	4.38 a v	79.8
Light	3.26 b v	26.1	2.70 b w	14.9

One possible explanation for this is that in deeper water the habit of *C. ciliaris* changes and the plant is more branched underwater and has more leaves on the surface, a habit similar to that of the *Paspalum* spp.

In both shallow and deep water the largest number of immature *Cx annulirostris* was among moderately dense grass and significantly fewer were found where the grass density was light (Table 4B). These results include the interaction between water depth and *C. ciliaris*. When the comparison is restricted to *Paspalum* spp. the numbers of immature *Cx annulirostris* in dense and moderately dense grass are similar irrespective of water depth and species of *Paspalum* (Table 4C). They are significantly higher (x3 to x7) than the numbers found where the grass density was light. In addition there is an indication that, when the grass cover was light, fewer immature *Cx annulirostris* were found in deeper water ($t=2.014$; $t_{0.05}=2.019$).

These observations showed that, in descending order, the density of immature *Cx annulirostris* was greatest in locations characterised by still water, supporting a moderate or dense grass cover of grasses which branched under the surface, and which were shaded for part of the day. This conclusion agrees with that of Laird (1988) who includes *Cx annulirostris* in his breeding sites grades A3-A6 lake edges, swamps and marshes, shallow permanent or temporary pools, all of which would provide still water in the presence of grass.

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